# AIRCRAFT SURVIVABILITY

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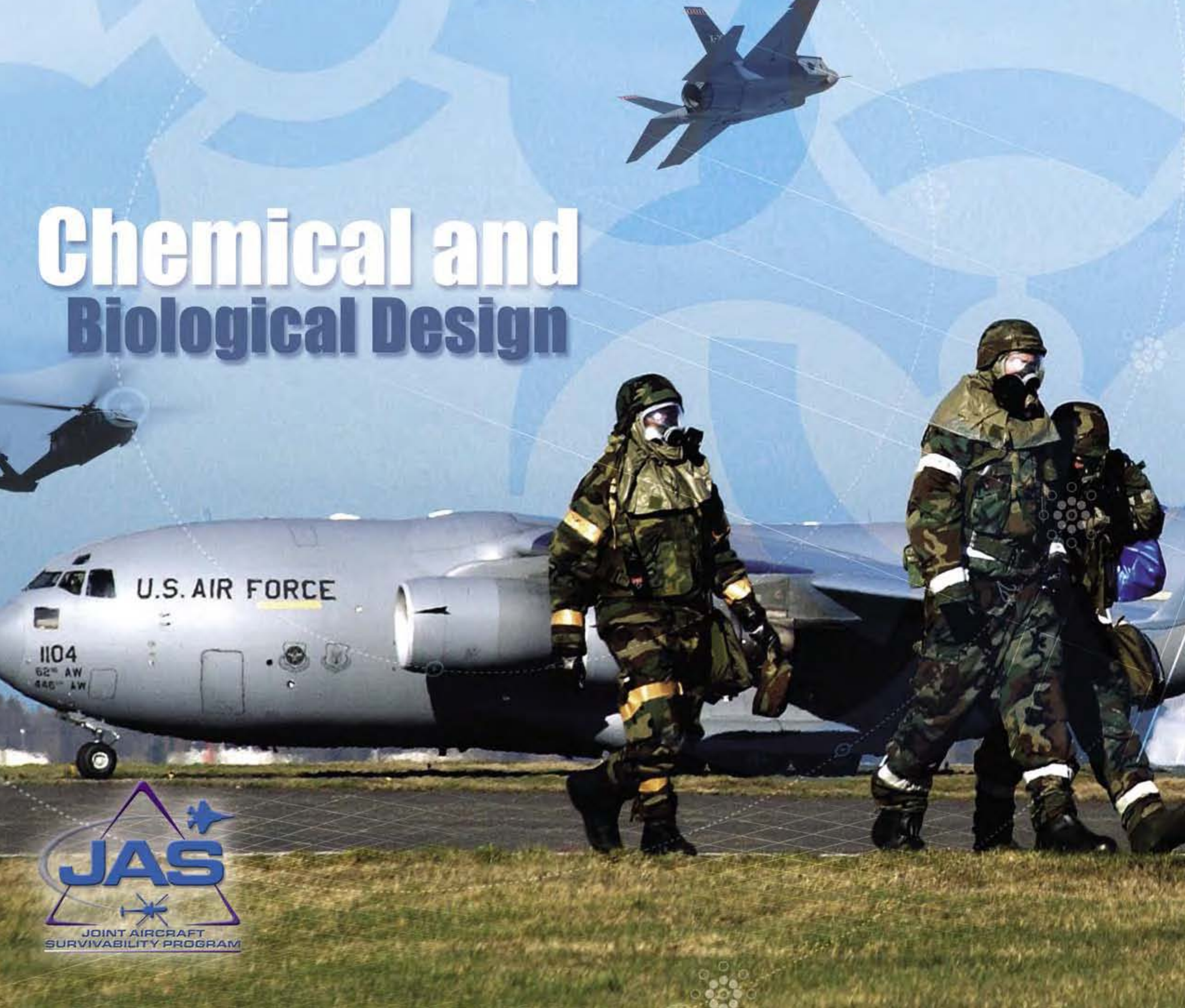
## Chemical and Biological Design



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# News Notes

■ by Dennis Lindell

## 2006 Aircraft Combat Survivability Short Course

The Joint Aircraft Survivability Program (JASP) recently completed a successful Aircraft Combat Survivability Short Course hosted by the Boeing Company in Seattle, WA, on 11–13 July 2006. The course was sponsored by the JASP with key participation and support from the Survivability/Vulnerability Information Analysis Center (SURVIAC). This was the third course offered over the past four years. Previous courses were held in Williamsburg, VA, and Dayton, OH. Seventy-five people attended the course where the highlight was a visit to the expanded Boeing Museum of Flight followed by dinner in the museum's View Lounge. The course was held at the Secret Not Releasable to Foreign Nationals/Governments/Non-US Citizens (NOFORN) classification level. The course agenda included all aspects of the survivability discipline, including susceptibility reduction, vulnerability reduction, and survivability modeling and simulation. The Joint Live Fire program and Joint Combat Assessment Team were also covered. A CD of all presentations and the materials provided at the course will be provided to each attendee. The JASP plans to offer this course annually as an outreach and educational service to the aircraft survivability community. Planning for next year's course is under way. Interested persons may contact Darnell Marbury at JASPO for further information and details about next year's course. He can be reached at 703/604-0817.

## Joint Service Battle Damage Assessment and Repair Capability Improvement Program (BCIP)

The warfighter has a limited number of aircraft and resources available during wartime. Aircraft Battle Damage Repair (ABDR), as it is referred to by the US Air Force and US Navy, or Battle Damage Assessment and Repair (BDAR), as it is referred to by the US Army, is critical to a warfighter's capability to maximize the number of aircraft available for sortie generation.

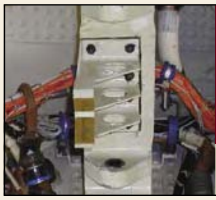
The US warfighter is currently engaged and has recently participated in combat operations, including Provide Promise, Deliberate Force, Joint Endeavor, Restore Hope, Operation Iraqi Freedom, and Operation Enduring Freedom. In these conflicts, aircraft have been returning with damage that needs to be repaired efficiently. Since Operation Desert Storm, there have been changes in the ABDR/BDAR concept of operations, threat effects, and the warfighting technology being employed. A number of new aircraft are also entering the fleet now or in the near future with new or exacerbated repair issues. During recent years, advancements in ABDR/BDAR have been slow to respond to these changes. In 2004, the Joint Aircraft Survivability Program (JASP) Office established the Joint Service BDAR Capability Improvement Program (BCIP) to address this problem. This purpose of this project, culminating this year, is to develop a roadmap to effectively upgrade the ABDR/BDAR capability of each Service to meet current and emerging warfighter requirements. Efforts over the last year involved interviews and data collection aimed at identifying problem areas or data gaps. An analysis is under way to quantify BDAR Research and Development (R&D) requirements, suggest projects to keep pace with advancing technology, and formulate BDAR capability improvements to enhance concepts, procedures, equipment, and training. A final report discussing the roadmap is anticipated near the end of the calendar year. The theme of the Summer 2007 issue of the Aircraft Survivability newsletter will be ABDR/BDAR.

## National Defense Industrial Association (NDIA) Asymmetric Threat Workshop

There is a growing concern in the US over the evolution of "asymmetric threats" to our military forces. The concern is so great that Congress recently passed a law requiring acquisition programs to include Key Performance Parameters (KPP) for countering asymmetric threats as part of their system requirements. However, there is no agreement on what constitutes an asymmetric threat, particularly to air systems, nor is there guidance to programs on how to incorporate asymmetric threat KPP into air systems' requirements. On 23 May 2006, the National Defense Industrial Association (NDIA) Combat Survivability Division (CSD) conducted a workshop to address those issues. The objective of the workshop was to identify the steps necessary to better understand, evaluate, and defeat asymmetric threats.

Attendees at the workshop arrived at a proposed definition of "asymmetric threat" that considers several axes: cost asymmetry (threat cost relative to target), employment asymmetry (innovative tactics), and effects asymmetry (relative impact from merely disruptive to catastrophic). Several scenarios were proposed to illustrate different types of asymmetric threats and their potential effects. Because this was a one-day workshop, developing KPP guidance was left for future efforts, but the workshop report includes a number of recommendations for future work.

The CSD plans to have a follow-on session on Asymmetric Threats and KPP at the annual NDIA Air Combat Survivability Symposium in Monterey, 07–09 November 2006. The Spring 2007 issue of the Aircraft Survivability newsletter will include articles on this workshop and on continuing efforts to define asymmetric threats. ■



# Systems Engineering Approach to Chemical/Biological Design

■ by Will Stewart and Hugh Griffis

Increased concern about asymmetric or non-traditional threats has highlighted the need to acquire military weapon systems able to operate and survive in a Chemical/Biological (CB) threat environment. The Department of Defense (DoD) has numerous programs with CB requirements to ensure robust combat capability within a CB environment.

The F-22 was the first fighter aircraft that required CB hardening and decontamination. To meet these requirements, the F-22 program established the overall CB design process for fighter aircraft. The F-35 fighter aircraft program, in its aggressive implementation of CB design led by Lucy Dighionno, has significantly extended and enhanced hardening and decontamination processes. The following discussion summarizes a proven acquisition process for assets that are CB hardened and able to be decontaminated. Four task areas categorize the process: Mission and Threat Vignettes, Warfighter Requirements, Performance-Based Specifications, and Design Evaluation.

## Mission and Threat Vignettes

Mission vignettes are composed of the attack scenario, threat type, combat operations, and threat challenges. To establish performance-based requirements that can be validated, each factor must be defined. The attack scenario defines where the air system encounters the threat and how the threat is delivered. An example attack scenario is an airbase that is simultaneously attacked by three surface-to-surface missiles. The airbase aircraft are exposed while parked or taxiing. The operational plan calls for continued flight operations from the contaminated airbase using contaminated aircraft. This simple scenario enables analysts to define the free-field threat environment, aircraft threat challenges, and operational needs.

Threat type must also be considered when defining threat descriptions. Chemical threats are classified into four categories: Nerve, Blister, Blood, or Choking agents. Bacteria, viruses, and toxins categorize biological threats. Since each agent will have different effects, each challenge limit should be directly traceable to individual chemical or biological agents.

Threat challenges will depend on the aircraft exposure zones. Recent CB assessments establish the free-field threat environment (liquid and/or aerosol) that may come in contact with the external regions of an aircraft. An aircraft has many different types of external surfaces such as external coatings, canopy, engine inlets, and engine exhaust nozzles. Some internal regions of the aircraft such as the wheels, wheel wells, and air vents, may be exposed to liquid and/or aerosol contaminates during typical operations. All internal regions of an aircraft that are exposed to open air are also subject to aerosol exposure.

## Warfighter Requirements

Warfighter requirements are related to operational approaches and the required warfighting capability. It is critical that the warfighter establish planned operational approaches as a function of time: prior to attack, during attack, and post attack. The operational approaches for post attack will be different before and after thorough decontamination.

In the early stage of hostilities, the potential of CB exposure to our troops requires the commander to manage risk to troops by altering personnel protection level and operational effectiveness. Personnel protection is obtained by wearing Nuclear, Biological, and Chemical (NBC) protection gear, which is called Mission-Oriented Protection Posture (MOPP). MOPP 4 provides the highest level of protection but degrades the ability of maintainers and pilots to conduct most mission tasks. Early definition of operational approaches enables a design team to provide additional flexibility to the commander.

During and after CB attack, personnel are in a dirty environment. The warfighter needs to establish the required operational effectiveness and duration of continued operations while in a dirty environment. Until a vehicle is thoroughly decontaminated, maintainers and pilots must wear adequate protection. Thorough decontamination is required to return a vehicle to non-restricted operations and standard logistics parts control.

## Performance-Based Specifications

Performance-based specifications translate warfighter requirements into critical system requirements. In general, CB specifications should address Vehicle and Support Equipment (VSE) compatibility, hardness, and decontamination.

Compatibility to personnel addresses ergonomic issues relative to performing mission tasks. The maintainer and pilot must complete mission tasks without compromising the integrity of the CB protective gear that is worn.

To eliminate the potential of tearing the protective overgarment or gloves, a VSE designer flows down detail design criteria for edges and corners. Criteria are also defined to allow ample spacing between buttons, switches, and controls.

CB hardness requires the VSE to retain the ability to operate during and after contamination. The vehicle's hardness and decontamination is based on top- coat and substrate materials, which the VSE designer selects based on the flowed-down detail design criteria. Proper selection of these material properties is critical to retaining functional capability. The external and internal regions of a vehicle have hundreds of different types of top-coat materials. This is problematic, as different materials can have significantly diverse hardness and decontamination efficacies. Figure 1 shows the complexity of internal and external surfaces.

Figure 2 shows a coated internal bay of an aircraft. Even though most internal panels and structural surface areas have been coated to facilitate hardness and decontamination, there are numerous parts that cannot be easily coated. These include electrical cables, insulation, tires, canopy, etc. Any part that is not resistant to CB challenge or decontaminable should be easily removed and replaced.

The decontamination process should provide the ability to undergo effective decontamination of the VSE without degrading functionality. Top-coat and substrate material properties can alter the effectiveness of the decontamination process and are therefore a key concern in the design process.

Table 1. Decontamination levels

| Level | Technique | Best Start Time | Benefit |
|---|---|---|---|
| Immediate | ■ Skin Decon<br>■ Personal Wipe Down<br>■ Operator Spray Down | ■ Before 1 minutes<br>■ Within 15 minutes | ■ Stops agent from penetrating |
| Operational | ■ MOPP Gear Exchange<br>■ Vehicle Wash Down | ■ Within 6 hours | ■ Possible temporary relief from MOPP<br>■ Limit liquid agent spread |
| Thorough | ■ Detailed Equipment/ Aircraft Decon | ■ When mission allows reconstitution | ■ Probable long-term MOPP reduction with minimum risk |

There are three levels of decontamination: Immediate, Operational, and Thorough. An excerpt from a table in the Army's Medical NBC Battlebook that details these three levels of decontamination is shown in Table 1. User requirements can define the level of decontamination to be used and how clean the asset should be after decontamination. The ability of a VSE to be decontaminated will depend on the design and the process used for decontamination.

## Design Evaluation

A logical approach to maximize the level of design verification can be adequately completed by performing incremental verification activities from the bottom up. This allows initial rudimentary testing to impact subsequent tests, thereby maximizing the probability of a successful decontamination at the VSE level. Design verification methods encompass analyses, modeling and simulation, live-agent and simulant tests, demonstrations, and design inspections.

The aircraft test-planning process starts with identifying families of materials that encompass several similar materials. Reducing the number of material families reduces test costs; however, this process increases the risk of overlooking specific materials that could lack characteristics for either hardness or decontaminability. Once material families are determined, small specimens (4.0 in x 4.0 in) should be tested to ascertain the material properties given exposure to live agents, simulates, and decontaminates.

Material test data is a long-lead, critical element of all CB design activities. Tests are selected depending on the challenge, the agents, and the question of interest (material hardness or decontaminability). The chemical liquid challenge that remains in the surface provides a contact hazard (or liquid percutaneous threshold). Contact hazard is the level at which a liquid chemical agent can be absorbed by unbroken skin. Chemical aerosol challenges

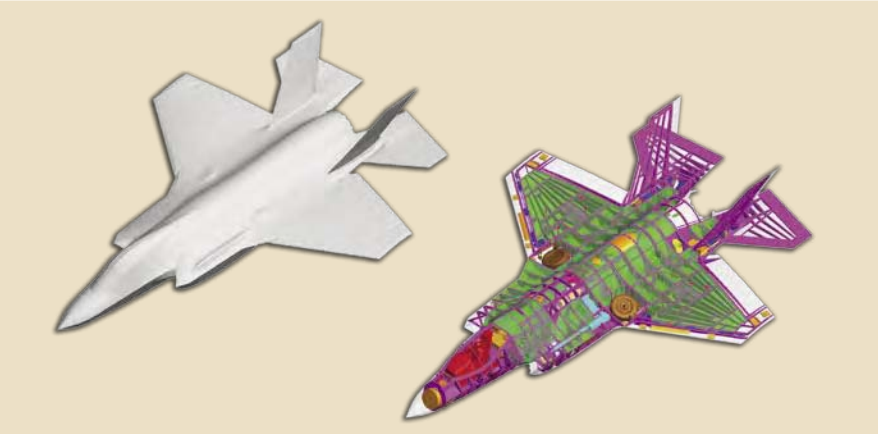


Figure 1. Lightning II external and internal regions

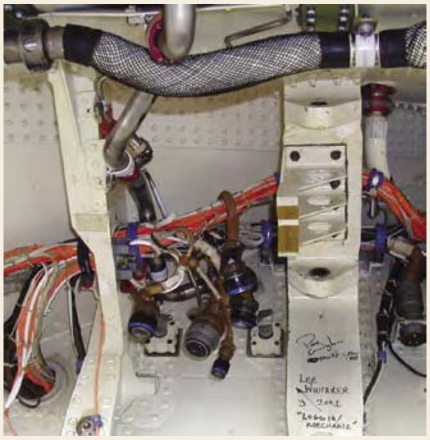


Figure 2. Coated internal bay

define the threshold needed to avoid miosis (or vapor percutaneous). Miosis is the constricting of the pupil and is a common side effect of many chemical agents. Human allowable contact and miosis thresholds are available for different levels of risk to the population—95%, 50%, and 5%. Allowable human exposure levels should use the conservative 5% damage threshold. Biological thresholds are determined by an allowable, minimum, infective dose defined by a set number of organisms.

Chemical liquid challenges also require physical property testing for materials. Property tests evaluate changes to material strength, color, signature, etc. Allowable changes in material properties depend on the specific design application. In general, biological threats do not have the same degrading effects on material properties and are therefore omitted from physical property testing for materials.

Once the specimens material testing indicates that the coating system is decontaminable, tests should be scaled upward to an assembly-level test article. Assembly-test articles should have representative geometry, surface area, clutter, wiring/plumbing, material/coatings, and instrumentation. Assembly-level test hardware can control air flow, temperature, and decontamination concentrations. These tests are particularly useful to down select competing decontamination options. Assembly-level test articles enable low-cost, repeatable contamination and decontamination to evaluate decontamination effectiveness.

Given effective decontamination at the assembly level, risks have been adequately reduced to proceed into system-level, full-vehicle testing. Scaling upward to full-vehicle decontamination has many additional risks because of complexities that were not captured in assembly tests. By following the overall process of incremental build-up design and evaluation, the overall risk and cost is minimized. The incremental material, assembly, and vehicle testing process is shown in Figure 3 below.

System-level tests can provide significant insight based on direct measurements of temperature, decontaminate and contaminate concentration, and air-flow velocity. Vehicle-level tests select a limited number of sampling points. Modern computers and software tools provide new options to predict results on all surfaces within complex geometric shapes such as aircraft. By using assembly-level and system-level tests to calibrate computer simulations, system engineers are expected to obtain high-quality predictions. The combination of testing and advanced computing methods is expected to reduce overall test schedule, cost, and risk.

## Conclusions

System engineering concepts are applied to establish a low-risk acquisition approach to design systems to operate in a CB environment. A well-formed acquisition program establishes Mission and Threat Vignettes, Warfighter Requirements, and Performance-Based Specifications. A well-written CB performance-based specification for compatibility, hardening, and decontamination requires significant insight of the threat, warfighter needs, and design processes. Early establishment of these critical elements is vital to the success of acquisition programs.

VSE material data against CB live agents, simulates, and decontaminates is critical to VSE designers. Generating material data is a long-lead task and historically is not available when needed. Hardness and decontamination information for VSE material data is required well in advance for the system design team.

Using system engineering principles reduces program schedule, costs, and risks by incrementally escalating testing from small material tests, to assembly-level tests, to full-up system-level tests. This build-up approach demonstrates results at the material level (lowest complexity), at assembly level (modest complexity), and finally at the system level (highest complexity). ■

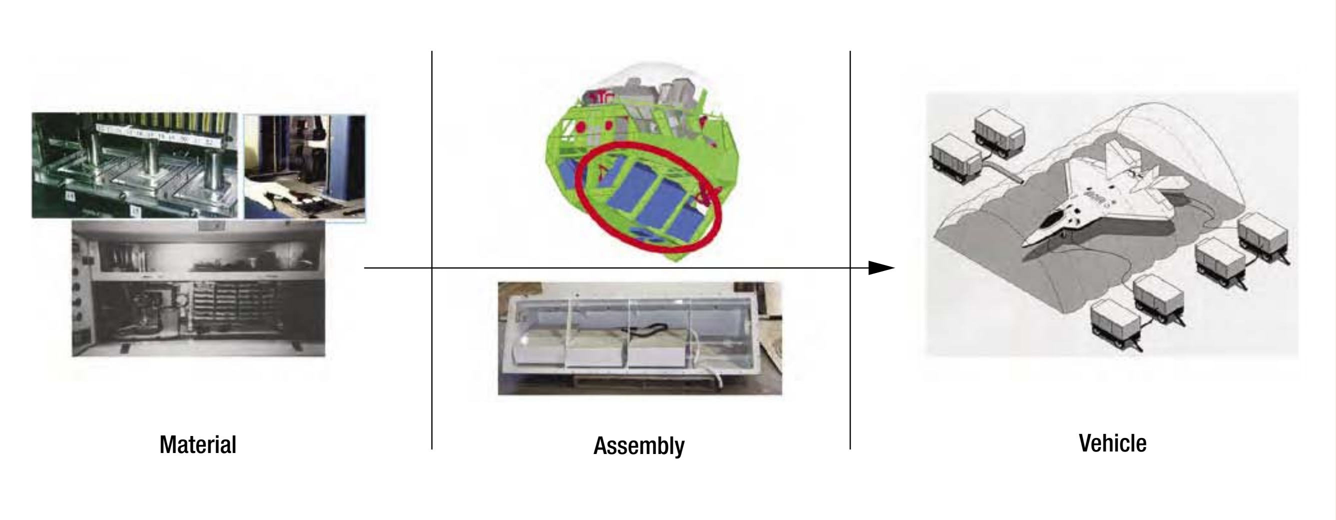



Figure 3. Incremental CB Testing

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## About the Authors

Hugh Griffis is a nationally recognized authority in the areas of chem/bio hardening, weapon system vulnerability, endgame analysis, and Live Fire Test and Evaluation (LFT&E). Mr. Griffis is an expert in the design of survivable aircraft, including considering the effects of chemical hardening and decontamination, high-power microwave hardening, and nuclear weapon effects. His current position is Division Chief of the Design, Analysis, and Simulation Division at the Aeronautical System Center's Directorate of Engineering (ASC/EN).

Will Stewart is a systems engineer at the Design, Analysis, and Simulation Division at ASC/EN. He has supported the Joint Strike Fighter (JSF) in planning, executing, and evaluating recent decontamination activities on a surrogate F-16 and in coupon-level testing. Mr. Stewart is also the project manager for an ongoing effort to develop a high-fidelity Computational Fluid Dynamics model and assessment for interior decontamination of the JSF.

# November 6, 2006 NDIA Aircraft Survivability Symposium Tutorials

### Morning Tutorial

8 AM, ME Auditorium, Naval Postgraduate School

### Introduction to Aircraft Combat Survivability

The morning tutorial is designed to give students and practicing engineers a basic introduction to aircraft combat survivability discipline and will focus on this year's theme, "Enhancing the Survivability of Civil & Military Aircraft." It will present history, terminology, concepts, measures, threats and threat effects, and methodology for assessing non-nuclear combat survivability analysis and design of both fixed-wing and rotary-wing aircraft. Additionally, recent technology will be discussed for enhancing the aircraft's survivability. The methodologies discussed will also be applicable to uninhabited air vehicles (UAVs), guided/cruise missiles, and ground vehicles. It is based upon Dr. Ball's 2nd edition of the AIAA textbook "The Fundamentals of Aircraft Combat Survivability Analysis and Design." Specific topics that will be covered include: An Overview of the Fundamentals, An Historical Perspective, Survivability Assessment, Designing for Survivability, and Enhancing Survivability.

**Instructor:**

CDR Mark Couch
Executive Officer
NROTC University of Illinois
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### Afternoon Tutorial

1 PM, ME Auditorium, Naval Postgraduate School

### Introduction to Infrared Countermeasures

Continued confrontations with adversaries armed with Man Portable Air Defense Systems (MANPADS) have escalated the urgency for aircraft protection. The afternoon tutorial is designed to give students and practicing engineers a basic introduction to aircraft combat IRCM systems that have been fielded to protect our war fighters. The presentation will begin with some relevant lessons learned from recent field operations in Iraq to address the capability of the threat and set the stage for providing some insight on the driving requirements for IRCM systems. IRCM systems are driven not only by threat requirements, but also by aircraft installation and operational considerations. A summary of these requirements will be covered to provide context for a presentation on the principles of operation of IRCM systems that are in production. Case studies of selected missile warning systems (AAR-44/47/54/57), IRCM lamp (ALQ-144/157/204) laser jammers (ATIRCM/DIRCM) along with decoy systems (ALE-47 & MJU7/8/10/ etc.) will be presented for several aircraft classes, including helicopters, transports, and fighter aircraft. These case studies will address system performance challenges and the key technologies that have enabled manufacturers to develop infrared countermeasure systems to defeat the proliferated MANPAD threat.

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# F-35 Lightning II Chemical/Biological (CB) Program

■ by Lucy DiGhionno and Will Stewart

Since the fall of the Soviet Union, accelerated proliferation of the Chemical/Biological (CB) threat has increased the likelihood that U.S. military personnel and weapon systems will be exposed to CB contaminants on the battlefield. Combat air vehicles must be capable of withstanding exposure to CB threats. As a result, there has been an increased emphasis on aircrew, maintainer, and air-system survivability in a CB environment.

A F-35 Lightning II Air Vehicle requirement was developed to retain mission capability without decontamination and with only routine servicing and inspection for a certain time period after exposure. This requirement defines CB hardness and covers the chemical threat-level concentration and duration and the biological threat minimum infective dose to ensure aircrew and maintainer survivability. The CB community uses the terms hardness and exposure in preference to vulnerable and susceptible. CB hardness is a measure of an air vehicle's ability to resist degradation by CB warfare agents. Materials selected in the design of an air vehicle must be capable of withstanding exposure to a contaminated environment without degradation of its critical properties for a specified period of time. Deployed units and commands must have the capacity to operate through and recover from a CB attack. This requirement addresses both air-system hardness and operational capability.

To ensure the Lightning II is fully compliant with CB decontamination requirements, a plan for incremental validation was established. This process progressed from material-property testing to subassembly testing to system-level testing. This testing process, coupled with modeling and simulation, confirms that requirements are being met at all stages of the design. Vigilant implementation of CB design requirements and proper selection of a sufficient decontamination process dramatically improves the ability of the system to be decontaminated.

## Decontamination Methodology

The ideal decontamination methodology would quickly decontaminate a system, not degrade any of the system components, and have a negligible impact on the environment. Unfortunately, there is no such magic solution for CB decontamination, although significant improvements have been made in recent years. New decontamination methods are more effective and less damaging than former techniques but still require the asset to be removed from operational status during decontamination. The type and quantity of contamination will have a direct impact on the length of time required for decontamination.

The decontamination methods that are being verified for Lightning II are Hot Air Decontamination (HAD) for chemical threats and Vaporized Hydrogen Peroxide (VHP®) for biological threats. Vaporized Hydrogen Peroxide is registered by STERIS Corporation and will henceforth be called VHP.

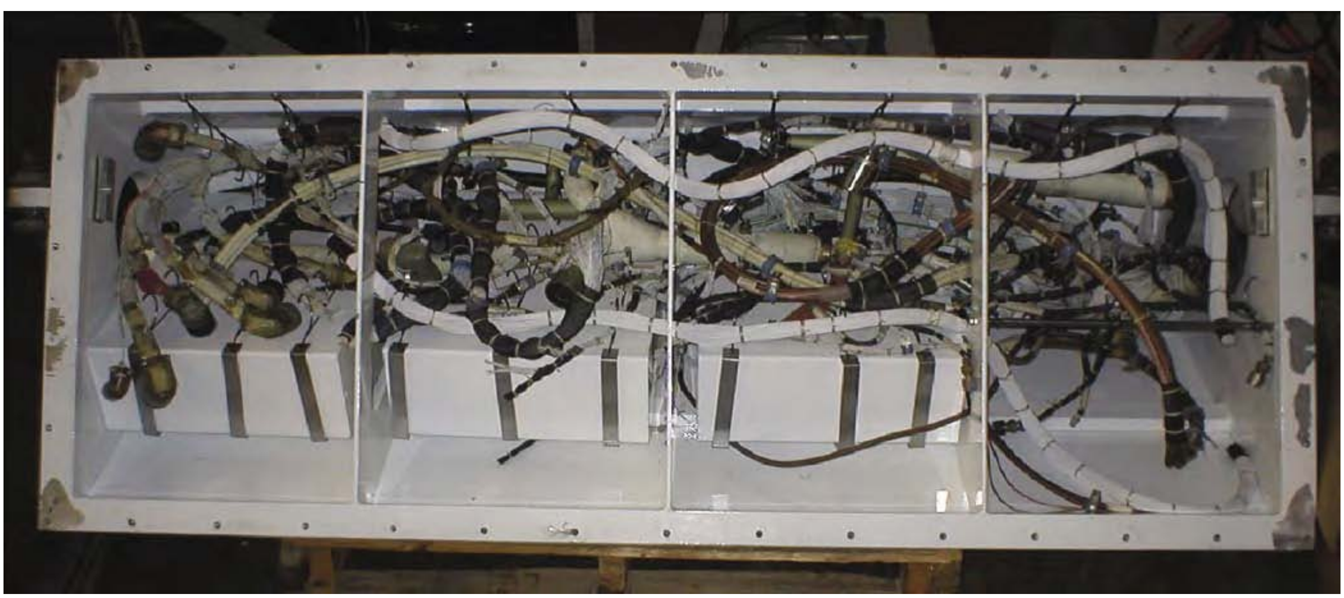

Figure 1. Cluttered electronics bay mock-up

Chemical threats naturally dissipate through natural weathering processes such as evaporation and chemical decomposition. Unfortunately, the natural weathering process is too time consuming to be beneficial to military assets that are essential to accomplishing mission objectives. HAD expedites the weathering process by introducing heated air with significant airflow in the vicinity of the contamination. The heated air facilitates chemical offgassing, while the airflow removes contaminant from the surface to prohibit the agent from being re-absorbed.

Biological threats and agents are living organisms that can be neutralized through a proven process such as VHP. Unlike chemical threats, biological contamination does not have to be physically removed from the asset once an organism is killed. VHP is also benign to the environment since it readily decomposes into water and oxygen.

## Aircraft Material Property Testing

There are numerous concerns that can be addressed through material-level testing. Material testing produces results that indicate whether a material can be decontaminated and how well the material will perform in a contaminated environment. It is obvious that materials used in subsystems that cannot be decontaminated will result in assemblies that cannot be decontaminated. The hardness performance of a material encompasses the quantifiable physical degradation caused by contamination or decontamination processes.

Both chemical agents and decontaminates may permanently damage materials. Chemical agents, once absorbed into certain materials, can alter their physical characteristics and degrade their ability to perform as designed. Numerous chemical and biological decontamination processes that are currently used have known adverse effects on materials. This highlights the need for a proven decontamination methodology that will effectively neutralize the threat without modifying material characteristics. Biological agents are innocuous to inorganic components, thus are not included in material testing.

To begin a material down selection process, a review of approximately 1,960 materials that were submitted by Lockheed Martin was conducted. Out of these, more than 350 unique materials were found. This number was then reduced to 30 material families that had conflicting or no data on chemical effects. These identified material families were used in material property testing that included offgassing, transfer hazard, sorption, hardness, and material damage assessment. The testing highlighted material families that are degraded by contact with either contaminates or proposed decontaminates. These materials should be exchanged for materials that are more resistant to contaminates and decontaminates, protected from contamination, or identified as components that must be removed and replaced after exposure.

Figure 2. Chemical decontamination preparation

## Subassembly Testing

Material testing provides valuable results without incorporating all the intricacies of testing a representative artifact. Subassembly tests provide results for an initial CB design evaluation and for verifying the feasibility of the proposed decontamination method. The fact that a material passes all physical property tests does not ensure that a subassembly test would be equally successful, because crevices, cracks, drainage, and other design characteristics are not apparent until the subassembly level. Figure 1 shows an electronics bay mock-up and emphasizes the difficulties that can be faced in decontaminating an operational aircraft. Any porous materials or areas that restrict airflow can be extremely difficult to decontaminate.

Subassembly tests are also the ideal medium to assess the efficacy of the proposed decontamination process. At this level of testing, the balance between controlling the decontamination process while capturing the realism of the system is optimized for process verification. A process that can be successfully demonstrated on a subassembly would have an increased probability of succeeding in a system-level assessment. Both VHP and HAD proved to be viable decontamination methods during subassembly testing.

## System-Level Assessment

Initially, the F-22 was selected as the Lightning II surrogate for the system-level assessment since it also has chemical hardness requirements. Unfortunately, the selected asset was not available when testing began. The F-16 aircraft is the next

best choice of currently available operational legacy aircraft for this testing, as it is being replaced by the Lightning II Air Vehicle and is also manufactured by Lockheed Martin. The F-16 was selected and used as an early Lightning II prototype to understand decontamination test issues before testing the actual aircraft. The F-16 used for testing had an operational engine and avionics systems for functional ground operations with all panels and doors in place. There are known differences in materials between the F-16 and the Lightning II that have been addressed by material-family testing at the coupon level. This system-level test was the first fully instrumented, tactical aircraft interior and exterior CB decontamination test performed.

A total of seven CB decontamination tests were performed on the F-16. Testing included three biological ingestion tests, three chemical ingestion tests, and one chemical exterior test. An ingestion test corresponds to the scenario in which an aircraft is covered during contamination but must be taxied or flown through a contaminated area. Since contaminate can be disseminated throughout both the exterior and interior of the aircraft, the decontamination process must also focus on both regions of the aircraft.

The F-16 was placed in a steel shelter for chemical decontamination. The shelter was heated to approximately 180°F while fans circulated the air inside the shelter. Thermocouples where strategically placed around the aircraft to enhance awareness of the thermodynamic characteristics of the process. Close monitoring of the thermocouples permitted the process to be controlled so that sensitive avionics equipment would not exceed temperature thresholds. Real-time chemical detection devices and post-decontamination sampling also provided insight to the decontamination process.

To expedite internal chemical decontamination, two augmentation flow locations on the forward avionics bays and two Environmental Control System (ECS) ports were used to introduce heated air inside the aircraft. ECS control valves were manipulated so that the interior of the aircraft could be decontaminated using the same flow paths that disseminated the contamination. Figure 2 shows the complexity of the HAD decontamination configuration for controlling the ECS valves, acquiring test data, and maintaining the desired temperature throughout the aircraft.

Biological decontamination was quite similar. The F-16 was placed in an inflatable shelter for decontamination. VHP was introduced to the interior of the aircraft using the same ECS and augmentation ports. The shelter was maintained at a slight negative pressure to ensure VHP was not leaking into the environment and to enable the VHP concentrations to be maintained at a concentration of 250 ppm. Fans circulated air inside the shelter to ensure a uniform VHP concentration.

These tests provided data that will be used to validate decontamination processes which will set the precedence for all tactical and fighter aircraft. Samples were taken before contamination, after contamination, and post decontamination in order to determine the efficacy of both decontamination processes. The test results are pending review and were not available at the time this article was written.

Figure 3. Biological decontamination preparation

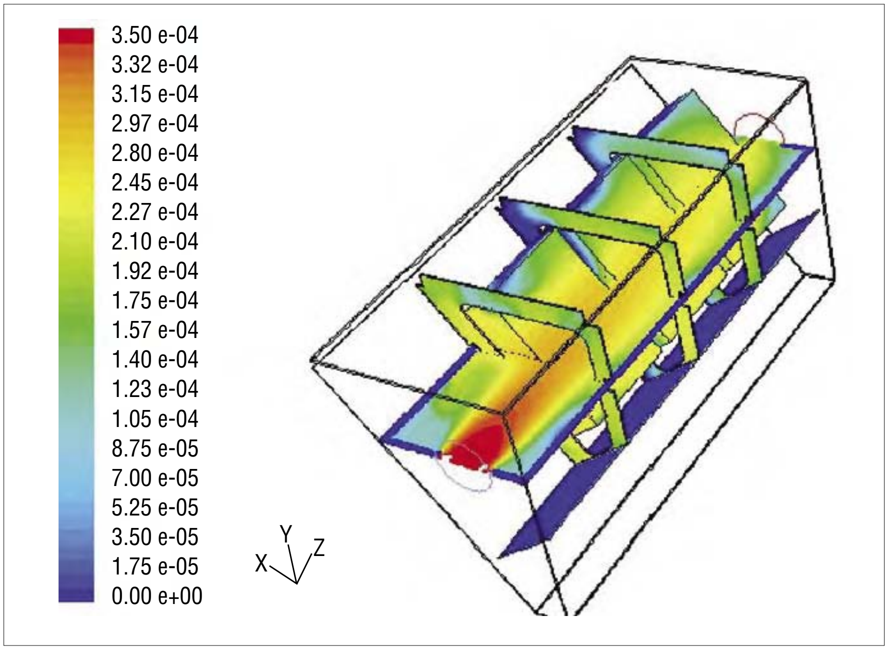


Figure 4. VHP dissemination in the avionics subassembly

## Modeling and Simulation

Modeling and Simulation (M&S) is being used to bridge the differences between the system-level test on the surrogate F-16 and the planned Lightning II aircraft-level test in 2012. A Computational Fluid Dynamics (CFD) model of a digital full-up Lightning II aircraft is being developed to evaluate the elements needed for a successful decontamination. The subassembly tests previously discussed were used to validate the modeling process.

Temperature and airflow, essential parameters for chemical decontamination, will be evaluated in the CFD model. Areas of the aircraft that do not achieve the desired temperature or have insufficient airflow will be more resistant to chemical decontamination and will be emphasized. The primary concern for successful biological decontamination is the proper dissemination of VHP. The VHP concentration throughout the Lightning II will be analyzed by M&S to locate areas that do not meet the required concentration level. Figure 4 shows a contour plot for VHP dissemination at 29 sec into the decontamination process for the subassembly test. At the ten-minute mark, VHP was completely disseminated throughout the subassembly model, which was consistent with test data from the actual subassembly test.

A key benefit in leveraging M&S to assess the decontamination process on a fully populated Lightning II is the ability to optimize the number and location of augmentation airflow inputs. If an aircraft configuration is modeled and produces results that indicate certain regions do not meet the decontamination goals, the configuration can be modified and re-analyzed. Leveraging M&S for this type of iterative design yields significant cost and time savings for downstream test activities.

## Conclusion

The Lightning II program, which has both a CB decontamination and vulnerability requirement, has performed decontamination techniques and material hardness testing at the material, subsystem, and system levels. Although the Lightning II program has scheduled a full aircraft CB simulant decontamination test in 2012, qualification by simulation testing on an available operational aircraft was performed before this test to mitigate risk. The testing performed on an F-16 demonstrated the complexities of the decontamination process and provided significant insights well in advance of the Lightning II CB validation tests. These insights will avoid an increase in testing costs and will shorten test time on this critical limited asset. ■

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## About the Authors


Lucy DiGhionno is the Air System Chemical and Biological Integrated Product Team (IPT) lead for the Joint Strike Fighter (JSF) program Office at the Naval Air Systems Command at Patuxent River, MD. Ms. DiGhionno has been involved with Chem/Bio design, test, and evaluation on the JSF program for four years. She has received both Bachelor's and Master's degrees in Chemical Engineering from Villanova University. She may be reached at lucy.dighionno@jsf.mil.

Will Stewart is a systems engineer at the Design, Analysis, and Simulation Division at ASC/EN. He has supported the JSF program in planning, executing, and evaluating recent decontamination activities on a surrogate F-16 and in coupon-level testing. Mr. Stewart is also the project manager for an ongoing effort to develop a high-fidelity Computational Fluid Dynamics model and assessment for interior decontamination of the JSF.

# The Chemical and Biological Defense Information Analysis Center (CBIAC)

■ by Dr. James King

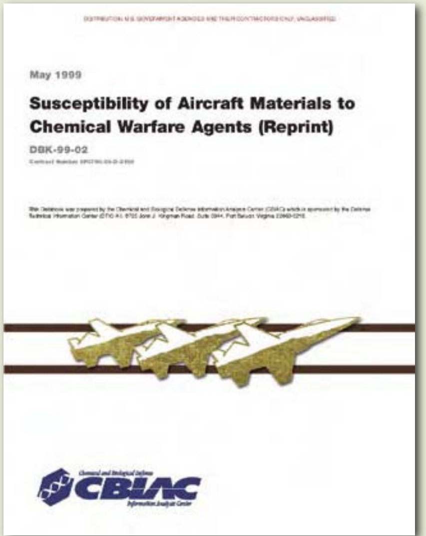
The Chemical and Biological Defense Information Analysis Center (CBIAC) is operated by Battelle Memorial Institute under contract to the Director Defense Research and Engineering (DDR&E), Defense Technical Information Center (DTIC), Information Analysis Center (IAC) Program. [1] IACs are chartered by DoD to provide support in key areas of technology such as chemical and biological defense, survivability and vulnerability, reliability, advanced materials, sensors, information assurance, weapons systems, software, and chemical propulsion. The CBIAC, one of these IACs, is a full-service Department of Defense (DoD) IAC. Established in 1986 and located on the Edgewood Area of Aberdeen Proving Ground, MD, the CBIAC serves as DoD's centralized source for Chemical and Biological Defense (CBD) information and technology. CBIAC's services and support are also available to all Federal agencies in addition to DoD, its contractors, and state and local government entities, including first responders.

The technical scope of the CBIAC is extremely broad and encompasses all aspects of defense against weapons of mass destruction for both DoD and Department of Homeland Security applications. This technical scope includes Analysis of Manufacturing Processes for NBC Defense Systems; Chemical and Physical Properties of CBD Materials; Chemical and Biological Identification; Combat Effectiveness; Counter Proliferation; Counter Terrorism; Decontamination, Defense Conversion and Dual-Use Technology Transfer, Demilitarization, Domestic Preparedness, Environmental Fate and Effects, Force Protection, Individual and Collective Protection, International Technology Proliferation and Arms Control, Medical Effects and Treatment; Nuclear, Biological and Chemical Survivability; Radiological and Nuclear Defense; Smoke and Obscurants; Toxic Industrial Chemicals and Toxic Industrial Materials; Toxicology; Treaty Verification and Compliance; and Warning and Identification.

The CBIAC offers two distinct components to support its users: the Core Program and the Technical Area Task (TAT) Program. Under the Core Program, the CBIAC is resourced by DTIC to acquire, process, generate, analyze, and disseminate Chemical, Biological, Radiological, and Nuclear (CBRN) defense and Homeland Security information to the DoD, other Federal agencies, DoD and Federal contractors, state and local governments, and first responders. In essence, the CBIAC Core Program is an already funded resource to assist in dealing with and understanding CBRN defense and Homeland Security technologies and their applications.

The principal CBIAC Core Program services include a range of no-cost support, such as responses to technical inquiries in any of our scope areas, newsletter subscriptions, database accounts through our extensive Web site, regular e-mail updates, and product sales. Although limited to four hours of analyst time per inquiry, the CBIAC inquiry program is one of its premier no-cost services, since the CBIAC excels at locating and analyzing information within its extensive technical scope. The program responds to approximately 900 inquiries each year, and usage is evenly split between Federal agencies and their supporting contractors. The CBIAC has responded to aircraft CB survivability inquiries from DoD and non-DoD Federal agencies, the military services, and supporting industry. Newsletter subscriptions are provided to all members of the CBRN Defense and Homeland Security communities at no charge, although approximately two-thirds of subscribers are members of Government agencies. The CBIAC newsletters also offer a vehicle to inform others of activities in relevant areas. Database accounts through the Web site make it possible for authorized users from both the Federal government and supporting contractors to perform their own bibliographic searches. Roughly,

Spray down of F-16 Fighting Falcon before its final chemical decontamination test




Sample CBIAC product

Federal government personnel hold two-thirds of these database accounts, with the rest used by supporting contractors. In most cases, these users will need to work through the CBIAC's inquiry service to obtain the actual documents or detailed information from identified documents of interest located through search results. E-mail updates provided to Federal government and contractors in roughly equal numbers address recent CBIAC activities and are provided at no cost. The content on the CBIAC Web site, except for the database, is available to all site visitors. The CBIAC Core Program also maintains a centralized repository of CBRN defense and Homeland Security scientific and technical information. This repository contains approximately 125,000 database records and over 100,000 document holdings, most of which are in electronic format. The CBIAC welcomes contributions to this repository and is pleased to work with contributors on the details. CBIAC product sales are limited to requestors who meet the requirements of the distribution statement for each item in our catalog. A restricted distribution item may be made available through the product sales program. The CBIAC will perform that function at no cost to the contributor.

As part of its Core Program, the CBIAC has focused on CB survivability of materials and systems, including those associated with aircraft. In addition to inquiry support in this area, the CBIAC maintains the Chemical Defense Materials Database, offers the Chemical Defense Materials Databook and the Susceptibility of Aircraft Materials to Chemical Warfare Agents handbook through its product program, and is actively involved in a DoD-level steering committee overseeing implementation of an updated chemical and biological contamination survivability database.

The CBIAC's TAT Program is a pre-competed task-order contract vehicle that provides support beyond the levels of the Core Program services. TATs services include information collection; databases; modeling and simulation; studies and analyses; basic and applied research and development (including laboratory, surety agent, and pathogen work); test and evaluation; technical consulting; training; conferences; testing of components, systems, and subsystems; engineering design, prototyping, and low-rate prduction in any of the CBIAC's scope areas. Knowledge management and development services are also available through the TAT program. The TAT Program is used most extensively by both DoD and other Federal Government agencies and also provides support to Government contractors. CBIAC TATs depend heavily on the information contained in the Core Program repository. All information produced through TATs is incorporated into the CBIAC repository, where it is used, consistent with distribution restrictions, to support future TAT efforts and to aid in preparing inquiry responses.

DoD's Information Analysis Centers (IACs), are a collection of specialized state-of-the-art research organizations sponsored by the Department of Defense.

The CBIAC's Core Program provides CBRN defense and Homeland Security services at little or no cost to authorized requestors from throughout the CBRN and Homeland Security communities, while the TAT program offers a competitively awarded, quick, convenient, and responsive contract mechanism to support larger-scale technical efforts that fall |within the CBIAC's scope. To learn more about the CBIAC, visit its Web site at http://www.cbiac.apgea.army.mil/or contact the CBIAC at the following location. ■

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## References

1. Information about DDR&E, DTIC, and IAC may be accessed through their respective Web sites: http://www.dod.mil/ddre/mainpage.htm, http://www.dtic.mil/dtic/index.html, http://iac.dtic.mil/

## About the Author

Dr. King is Deputy Director of the Chemical CBIAC. He has more than 29 years of research and development experience, including 22 years of active-duty military service at levels ranging from research scientist to senior program administrator, with more than 19 years of that experience in CBRN defense.

# Threat Effects in Aircraft Combat Survivability DVD Now Available

by Robert E. Ball, Jr.

The documentary video project, *Threat Effects in Aircraft Combat Survivability*, funded by the Joint Aircraft Survivability Program Office (JASPO), received its first screening before an enthusiastic audience at the recent Threat Effects Weapons Seminar held at Eglin Air Force Base. This project substantially updates the material presented in the original *Threat Effects…*, which was funded by the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) in 1986. A stand-alone DVD of the updated *Threat Effects*...will soon be available from Survivability/Vulnerability Information Analysis Center (SURVIAC).

This documentary uniquely presents the primary threat weapons to aircraft and the ballistic response or "effect" of an aircraft when hit by a threat. It contains combat and gun-camera footage and both lethality and survivability test analysis video, all of which are combined and edited to demonstrate the cause and effect relationship between threats and their effect on an aircraft on the battlefield. The benefits gained from using technologies in vulnerability reduction will further increase the viewers' interest in, knowledge of, and appreciation for the survivability discipline.

Scenes of encounters between US aircraft and anti-aircraft threats photographed during Operations Iraqi Freedom, Enduring Freedom, Desert Storm, Restore Hope, the Vietnam conflict, and other encounters, including the second Chechnyan war, vividly illustrate the threats' lethality, their effects, and the subsequent damage processes that occurred in these encounters. The anti-aircraft threats presented in this documentary include air-to-air missiles, surface-to-air missiles, Man-Portable Air Defense Systems (MANPADS), Rocket-Propelled Grenades (RPGs), Anti-Aircraft Artilery (AAA), and small arms. Lethality test analysis video of these threats reveals the details of their fusing and the generation of different types of damage mechanisms.

The combat and gun-camera footage and survivability test video in *Threat Effects…* feature current frontline aircraft including the AH-1, A-10, AH-64, F-14, F-15, F-16, F/A-18A/B/C/DE/F, B-52, C-130, H-60, H-47, UH-1, the JSF during its developmental testing phase, and the civilian Airbus A300.

Survivability analysis video of ballistic tests conducted on selected aircraft illustrates how an aircraft's systems are affected by a threat's impact. The tested aircraft systems include fuel, propulsion, flight control, armament, crew, avionics, structural, electrical power, power train, and rotor blades.

The updated *Threat Effects…*concludes by presenting some positive effects achieved by incorporating various vulnerability reduction features, either by altering the aircraft's design or by adding equipment to prevent a system's kill modes from occurring.

The original 1986 version of *Threat Effects…*has been seen by thousands of viewers, including members of the four services, Department of Defense, and contractor personnel. It is anticipated that thousands of additional viewers will watch this update. The JASPO believes that as these new viewers gain knowledge of the information contained within the updated *Threat Effects*..., they can more effectively integrate survivability—its tenets, technologies, and tactics—into all phases of aircraft procurement, design, and combat operations.

The production of *Threat Effects…*received strong support from the survivability, lethality, intelligence, and operational


Screen shot from the *Threat Effects in Aircraft Combat Survivability* DVD

communities. Sources for some material included in the project were as follows:

- US Air Force Aerospace Vehicle Survivability Facility
- US Army Survivability/Lethality Analysis Directorate, Applied Technology Laboratories, and 160th Special Operations Aviation Regiment (Airborne)
- US Navy Weapons Survivability Laboratory and the Detonation Science Branch at the Naval Air Warfare Center
- National Ground Intelligence Center
- Defense Visual Information Center
- RHAMM Technologies
- Booz Allen Hamilton
- SURVICE Engineering Company
- SURVIAC

Additional video for *Threat Effects*…was shot by the project's producer and director, Robert E. Ball, Jr.

The JASPO is currently funding a training video project for the Joint Combat Assessment Team (JCAT), which is also produced by Mr. Ball and SURVICE Engineering. This new project will provide incoming JCAT members and other designated personnel with threat and damage training, threat-induced damage identification training, and an introduction to both aircraft design features and survivability features. The project will also focus on the JCAT's purpose, processes, tenets, and real-world benefits, including the advantages gained from incorporating aircraft survivability features. ■

The *Threat Effects*…updated DVD is *For Official Use Only (FOUO)* and not for public release. Distribution authorized to US Government Agencies and their contractors only; critical technology; July 2006. Requests for this DVD should be referred to the:

JASPO Program Manager
Crystal Gateway #4, Suite 1103,
200 12th Street South
Arlington, VA 22202.

## About the Author

Mr. Robert Ball Jr. is a consultant for SURVICE Engineering Company of Belcamp, MD. He produced the original, 1986 documentary of *Threat Effects*… and several other projects for the Joint Live Fire (JLF) and the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME). He also wrote and directed the fourteen-episode American Warriors series of heroic stories of Gulf War veterans for cable television. Non-military themed projects include music videos for the Warner Music Group and a documentary on gangs, which is currently in production. He is based is Los Angeles, CA, where he maintains his office, studio, and post-production facility.

Screen shots from the *Threat Effects in Aircraft Combat Survivability* DVD

# Daniel C. Cyphers

## Excellence in Survivability

■ by John M. Vice

The Joint Aircraft Survivability Program Office (JASPO) is pleased to recognize Mr. Dan Cyphers for Excellence in Survivability. Mr. Cyphers is Vice President and Manager of Dayton Operations for Skyward, Ltd., and he is responsible for all technical and management actions in support of Skyward's clients.

Dan has 20 years of professional experience, including 15 years in both aircraft survivability/vulnerability analysis and ballistic testing. His experience also includes advanced material evaluations for space-based strategic defense applications, developing a phased-array antenna radar diagnostic tool, participating in the genesis of lean manufacturing principals in aircraft development, and technology-transfer activities related to U.S. Air Force (USAF) material development. He received a Bachelor of Mechanical Engineering degree in 1986 and an MS degree in Aerospace Engineering in 1991, both from the University of Dayton (UD).

Dan joined Booz Allen Hamilton as a part-time technical aide working on several tasks for the Survivability/Vulnerability Information Analysis Center (SURVIAC) while studying at UD. Thus began his involvement in survivability/vulnerability activities. Early on, he led the development of a computerized geometric target description of the F-16A aircraft for use in missile endgame simulations and performed a study comparing aeronautical system component vulnerability and ballistic test databases. Later, he supported the USAF Joint Live Fire (JLF) program in performing ballistic and structural load test-damage inspections of F-15 and F-16 wings and documented the results. He also participated in a study to assist the Advanced Combat Maintenance Technology Program in defining the requirements and developing an Aircraft Battle Damage Repair (ABDR) methodology for application throughout an aircraft's life cycle.

Wanting to broaden his technical scope and venture into space activities after his aircraft experience, Dan joined W.J. Schafer Associates, Inc. in 1989, where he was involved in examining advanced materials and processes for technology applications in space-based ballistic missile defense systems, particularly for the Strategic Defense Initiative Organization (SDIO). He performed finite-element analysis of candidate materials and designs and provided technical and program support to the Advanced Materials for Space Structures program in SDIO's Key Technology Program. This support included assisting in recommending programs, candidate space experiments, and demonstration opportunities and in directing the Vibration Suppression Subtask. On one effort, he conducted a worldwide survey of space environmental effects ground-test facilities, particularly atomic oxygen simulation facilities, and assessed their applicability to space-system development. After the merger of the local W.J. Schafer office with Lawrence Associates, Inc., Dan became involved in manufacturing technology analysis. He also performed the mechanical engineering analysis necessary to demonstrate a diagnostic tool for phased-array antenna radars using infrared imaging, and he assisted in organizing the Air Forces' Lean Aerospace Initiative to implement "lean" manufacturing principles into the defense aircraft industry. He participated in efforts to transition Air Force Materials Directorate technology to Air Force systems and technology transfer to industry.

Dan returned to Booz Allen in 1994, where he rose to the position of Associate with wide-ranging management and technical responsibilities in aircraft survivability. He assisted the Air Force Research Laboratory in developing a test plan for ballistic tests of a C-17A wing fuel tank. As part of the C-17 Live Fire Test & Evaluation (LFT&E) program, he coordinated data-collection efforts, a comprehensive post-test hydrodynamic ram data analysis involving subcontractors and consultants, and the documentation of test and analysis results into a final report. He led another effort to verify that repairs conducted on the wing between each test returned the structure to its original strength. Mr. Cyphers was a team leader on a comparative vulnerability analysis of candidate Close Air Support aircraft. He led the vulnerability assessment of the A-10 aircraft and was responsible for determining vulnerability analysis standards for the study.

Mr. Cyphers broadened his program-management skills as he led efforts in planning, conducting, and documenting the results of the B-1 LFT&E program. He managed test and analysis activities for at least six test series that made up this program, which involved technical areas such as dry bay fire, ullage explosion, hydrodynamic ram, and characterizing JP-8 jet fuel and 40mm high-explosive ammunition.

Since 1997, Dan has continued expanding his survivability/vulnerability credentials with Skyward. He has led support to the 46th Test Wing's Aerospace Survivability and Safety Flight (ASSF) on a number of live-fire test and analysis programs. His technical responsibilities have included ballistic test planning, test site support, data analysis, test reporting, vulnerability assessment input development, and ABDR documentation. He has been a lead contractor engineer and manager for a number of JLF and LFT&E programs, most notably the numerous ballistic test series and vulnerability assessment activities involved in the C-130J and C-130 Avionics Modernization Program LFT&E efforts. Most recently, Dan led efforts within Skyward to develop an Enhanced Powder Panel fire-protection device for protection against ballistic vulnerability. This successful effort started with a research and development feasibility study and has taken the device to the brink of commercialization. In his current position, Dan is also leading Skyward efforts to examine the current capability of ABDR in each Service and to develop a plan for improving this capability in the future.

In recognition of his contributions to the ASSF, Dan was recognized as the Flight's Professional Services Contractor of the Year for 2004. Dan was cited for exceeding expectations in accepting responsibility for ensuring completion of the many tasks he led on behalf of the Flight. Further, it was Dan's contributions to the ASSF mission, along with his technical expertise, his "can-do" attitude, and his willingness to go the extra mile that resulted in his winning this prestigious recognition.

Dan is a member of the American Institute of Aeronautics and Astronautics (AIAA) and the National Defense Industrial Association. With AIAA, Dan is part of the most recent group of members to be elevated to the grade of Associate Fellow, an honor that recognizes his technical accomplishments in his professional career and his contributions to AIAA. One key element of his AIAA involvement is his service on the AIAA Survivability Technical Committee. Dan has also served as co-chair and venue chairman for the Dayton-Cincinnati AIAA Chapter's 2003 Passport to Flight Committee. Passport to Flight was a very successful children's program during the Dayton-area centennial celebration of the Wright Brothers' first flight. For these contributions, Dan and his fellow team members were awarded the 2004 AIAA Dayton-Cincinnati Section Chairman's Award.

In his spare time, Dan is often referred to as "Coach": He coaches his three children year-round in baseball, soccer, and basketball. As members of the athletic board, he and his wife, Jana, have assisted in re-establishing a Catholic Youth Organization (CYO) sports program at their children's school. Dan participates in civic and charitable activities through his membership in the Knights of Columbus.

It is with great pleasure that the JASPO honors Dan Cyphers for his Excellence in Survivability contributions to the survivability discipline and the warfighter. ■

## About the Author

John M. Vice is President of Skyward, Ltd. A long-time member of the aircraft survivability community, Mr. Vice received a BS degree in Aeronautical Engineering from the University of Wyoming and an MS degree in Aerospace-Mechanical Engineering from the Air Force Institute of Technology. He may be reached at 828/697-5265 or jvice@skywardltd.com.

# Combat Helicopters—The Ballistic and Nuclear, Biological, and Chemical Threat Challenge

■ by Gerald J. Burblis

The ballistic threat continues to be primary to combat helicopters, while the Nuclear, Biological, and Chemical (NBC) threat has remained a viable one, even though its use in the most recent conflicts has not materialized. For this reason, it is essential that future combat systems be equipped to resist the damaging effects of both ballistic and NBC threats. The intent of this article will be to heighten awareness of the damaging characteristics of each threat and to offer insight into those features that reduce vulnerability and can enhance a helicopter's ability to operate effectively in a multifaceted threat arena. Some vulnerability-reduction features that will be discussed have been incorporated into today's air vehicles, while others have been developed and tested but have not reached a state of technical maturity that would permit their introduction into the current military inventory.

## Ballistic Survivability

Current conflicts in Afghanistan and Iraq have increased the need for improved ballistic protection for helicopter operations in support of ground forces. Today's helicopter missions have changed dramatically from anti-tank and insertion missions, near or at the forward edge of the battlefield, to patrolling urban landscapes, escorting convoys, and locating and suppressing insurgents. The new missions have significantly increased the risk of ballistic damage to air vehicles. Closer proximity to the enemy permits even the Rocket Propelled Grenade(RPG) anti-tank weapon to become a viable threat.

Even with the changes found on today's battlefields, the basic fundamentals of helicopter survivability still apply. The use of flight-critical system, subsystem, and component separation and redundancy dramatically reduces the loss of a system by ballistic impact. However, today's evolving technologies, both in analytical assessment and product development, are making major strides toward improving an air vehicle's ability to incur and resist the effects of ballistic damage. Assessment methodologies have improved, thanks to the results obtained from recent Live Fire Test & Evaluation (LFT&E) ballistic testing during the past eight years. This has led to an improvement in the Probability-of-Damage-Given-a-Hit (Pd/h) database.

To predict fragmentation damage, computer modeling and simulation for enhanced, High-Explosive Incendiary (HEI), using finite-element modeling and blast-overpressure testing data, have resulted in more accurately predictable component damage before actual testing. Advances in computer technology have resulted in the ability to produce target-model descriptions with an increased level of detail. The standard 26-view assessment approach has also been expanded to permit an infinite number of shotline assessment angles in an effort to refine the results of vulnerable areas and to better identify major contributors. This could result in less risk reduction and LFT&E testing in the future.

HH-60G Pave Hawk

Even though predictive assessment results are coming closer to actual ballistic testing results, anomalies do still occur. During recent testing, ullage detonations within a fuel cell occurred without the initial incendiary ever reaching the ullage atmosphere. The incendiary functioned externally, brought particles along with it into the fuel, and ignited the air within the cavitation space behind the projectile. This minor explosion then broke the surface of the fuel and subsequently ignited the ullage above the fuel. In another test, a fuel fire was not extinguished because cooler fuel engulfed the sensors before they could react to the fuel fire above the fuel, which resulted in a non-functioning fire-suppressant system. Both occurrences are not normal events but do demonstrate that predictive analysis can go only so far and that actual testing is still required.

Ballistic testing of flight-critical components is essential to developing any helicopter system. Using risk-reduction ballistic testing early in a program's development will benefit the air vehicle manufacturer earlier in the design process and will thereby satisfy future LFT&E testing requirements.

Major advances have been made in the LFT&E arena through dynamic testing rather than the previously used static article testing approach. By using full-up, tethered, and fully operating systems for more realistic dynamic testing has produced realistic combat-damage simula-

tion results. This has been especially true for tests on the following systems:

- Rotor blades
- Fuel systems
- Drive-train components
- Engines

We can now determine the synergistic effects on other nearby operating systems from a given Armor-Piercing Incendiary (API) or HEI impact on a particular component. This approach permits us to determine potential fire-ignition sources, hydrodynamic ram effects, or fragmentation damage. Other innovative technologies have undergone recent testing, including the following:

- Hard composite armor technology advances
- A soft composite armor concepts under evaluation
- Testing of an ionomer overwrap material for fuel line and cell sealing has produced excellent results. The ability of a relatively thin sheet of material to incur damage from a penetrating projectile and not produce fuel leakage on a previously unprotected engine fuel-supply line is impressive. The material is low cost, light weight, and easily installed; it could also be used to limit fuel leakage by being installed on the exterior surface of non-self- sealing fuel cells.
- Significant advances have been made in advanced powder pack designs to permit easier fabrication and contouring to meet specific applications and unique features. This permits greater dispersion of the powder, in a shorter time frame, over a larger area.
- Fire-extinguishing systems have now been developed that use a pressurized tube for releasing the extinguishing agent. The nitrogen-filled tube, routed into the area to be protected, acts as a triggering device and reacts to fuel melting or perforating the tube to initiate the release of the extinguishing agent at the point of damage.

Ballistic survivability will continue to improve as evolving technologies associated with innovative material development, improved manufacturing processes, additional dynamic LFT&E testing, and analytical computer assessment capabilities come closer to matching actual ballistic testing results.

## NBC Survivability

Other threats exist that must be protected against, even though they have not had recent battlefield usage. The NBC threat is real, and its use could be devastating to an unprotected air vehicle operating in a low-altitude combat environment.

Compatibility of new and innovative NBC survivability equipment with current or developing helicopter designs is a key factor. To facilitate use of state-of-the-art NBC survivability equipment, a modular installation approach should be considered. This approach offers many benefits in specific areas, some of which include the following:

- Provides new air vehicle production flexibility, as each successive production lot could have different protective features incorporated independently of the previous lot.
- Permits older air vehicles in the current inventory to be upgraded in a phased process.
- Reduces annual cost and permits budget flexibility for when and where air vehicles are upgraded.
- As new threats emerge, can assist in rapid design changes and modifications through the use of trade study.

Optimizing NBC survivability protection requires a multi-faceted approach that encompasses detection, material hardening, filtration, and decontamination.

### Detection

Detection and avoidance offer the best solution for low-altitude helicopter combat operations. Using a look-ahead detector on the air vehicle, or on another dedicated air vehicle within the squadron, offers maximum response time before a threat is encountered during flight operations. Using manned ground or airborne reconnaissance offers real-time situational awareness of the threats on the battlefield. Other options include using an Unmanned Air Vehicle (UAV) with onboard detectors or distributing deployable sensors in advance of flight operations. Maintaining knowledge of threat presence in specific areas of potential operations, will lessen the impact of the biological and chemical threat. Significant advances have been made in detector capability, with major reductions in system size and weight. Using a modular look-ahead or point chemical detector offers the advantage of both weight and cost savings. When needed, the detector would be mounted on a weapons-store point on a designated air vehicle. This would eliminate the need to continuously carry the weight burden on all air vehicles in the squadron during

MQ-1 Predator unmanned aerial vehicle

any form of operation, including training missions. This approach would also be less costly, as fewer detector units would be required, and keeping detectors off helicopters during routine missions would also limit their potential for being damaged. Detecting and quantifying a biological threat from an airborne platform still remains a challenge.

## Material Hardening

The minimum approach to NBC hardening would be to screen all materials used in fabricating an air vehicle to determine its resistance to degradation from exposure to the NBC threat, with the primary focus on chemical threat agents. Chemical agents produce more damaging effects on equipment than either biological agents or radioactive fallout. Material evaluation early in a helicopter's design phase will help to highlight those materials most susceptible to degradation. Once identified, recommendations can be made to enhance survivability by performing one or more of the following:

- Determine if the susceptible material is located in an area that NBC contaminants can reach during normal operations. If not, then no protection is required, since the location within the air vehicle provides a form of synergistic protection.
- If acceptable, replace the susceptible material with a proven resistant material.
- Recommend use of a protective coating.
- Provide filtration and over-pressurization for protection.
- If none of the above can be incorporated, provide operational instructions stating that any suspected exposure to NBC threat agents requires immediate inspection of this item and potential replacement if degraded. This has to be carried as a logistics burden.

Determining a material's resistance to chemical agents has become more difficult over the past decade because many synergistic materials have been developed that comprise a combination of basic materials. For this reason, it is essential that material coupon testing against live agent continues on a regular basis to ensure that an accurate materials degradation database is maintained for NBC assessment and screening purposes. Making this research and development investment in advance of a battlefield encounter could be the difference between a flyable *vs.* a non-flyable air vehicle and squadron after a single exposure.

## Filtration

Newer NBC filtration technologies are present but have not been brought to operational status. Any filtration system should be used in conjunction with a cockpit and electronics bay over-pressurization system to prevent entry of NBC contaminants into a helicopter's interior. Space, weight, and power consumption have always been the concern for incorporating any filtration system on an air vehicle, and this remains much the same today. Carbon based filtration systems continue to be the systems of choice, but they have limitations that must be addressed if we are to improve this technology for future battlefield operations. A layered filter bed approach is currently used to remove the initial deadly nerve and blister agent threats, followed by carbon layers to remove high-volatility threats such as blood agents. The ability of carbon to have limited resistance to humidity saturation is a detriment, as is not having a way to effectively monitor residual tilter capability following exposure to a contaminated battlefield.

Effective NBC filtration and interior over-pressurization features will remain a goal for future helicopter designs. However, until the threat materializes on the battlefield, the emphasis for innovative filtration development will be limited.

Marine CH-53 Super Stallion

## Decontamination

In the past, U.S. Army doctrine dictated that when a unit became contaminated, soldiers stopped fighting, pulled out of battle, and found a chemical unit to perform a cleanup. This process was time consuming and not tactically or logistically feasible. With an aggressor's capability to contaminate large areas of terrain, a contamination free environment after every chemical attack is impracticable if not impossible. Today's emphasis is on "fighting dirty" and conducting hasty decontamination, combined with natural weathering to reduce chemical or biological hazards.

An air vehicle is expected to complete one full combat day, equal to 12 hours, and then be returned for spot decontamination, refueling and re-arming, visual inspection, and maintenance, as required.

The operational requirements for an air vehicle following a single NBC attack are to be able to effectively perform its follow-on missions with only the crew performance degradation associated with wearing the Mission Orientated Protective Posture (MOPP) IV protective ensemble. During the threat of a potential NBC encounter, wearing the MOPP ensemble is an operational requirement in condition Level III or Level IV. An air vehicle will be re-armed and refueled at the Forward Arming and Refueling Point (FARP) and returned to mission status. Any decontamination performed at the FARP will be a spot decontamination and involve only those areas, latches, handles, doors, and covers associated with immediate operations normally performed at the FARP.

The air vehicle will fight "dirty" in an NBC contaminated environment until servicing requirements or equipment failure mandates that it be withdrawn from operational service. It will then be removed to a dedicated rear area for deliberate decontamination and subsequent maintenance.

The four principles of decontamination are:

- as soon as possible,
- only what is necessary,
- as far forward as possible, and
- prioritized.

Unit personnel conduct spot decontamination, whereas a chemical decontamination unit usually conducts deliberate decontamination. Although spot decontamination reduces the hazard level, personnel must still use protective equipment. The goal of deliberate decontamination is to reduce the hazard to a level at which protective equipment is no longer required.

Aircraft decontamination poses unique challenges to commanders. They must decide when to conduct the various levels of decontamination. Deliberate decontamination sites are established by chemical units, usually in the rear areas. The supported units conduct their own personnel and equipment decontamination. The chemical unit decontaminates vehicles, provides technical assistance, and supervises the entire site. The supported aviation unit must coordinate closely with the chemical unit to ensure that aviators do not land contaminated aircraft in clean areas.

Several techniques may be used to decontaminate aircraft. An effective method is the one-step method, in which air vehicles are sequenced into a particular area, shut down, decontaminated, and returned to duty. Squadron NBC defense personnel and the supporting chemical unit jointly establish the decontamination site. The entire aircraft or specific areas are washed with hot, soapy water and rinsed. This sequence is continued until all squadron elements have completed the decontamination process.

Because aircraft components are sensitive to caustic solutions, special decontamination procedures have been developed. On-site commanders must combine special procedures with decontamination principles and determine where and when to conduct decontamination operations. Because aircrews fly in MOPP 4 gear, commanders must compare how decontamination *vs.* no decontamination will affect the mission.

Only approved cleaning compounds may be used to decontaminate aircraft. Caustic decontaminants, such as Decontamination Solution Number Two (DS2), Super Tropical Bleaches (STBs), or sodium hypochlorite, are not considered safe, but their use under field-expedient combat conditions must be considered. Even though some may no longer be in active inventory, they may appear on the battlefield from previous stockpiles. Soap and water, kerosene, JP-8, and diesel fuels are approved as decontaminants on selected parts. ■

## About the Author

Gerald J. Burblis is the Survivability Manager of the Survivability Group at Sikorsky Aircraft. He attended Northrop Institute of Technology in Inglewood, CA, where he majored in Aerospace Engineering. Mr. Burblis has more than 41 years of aeronautical experience at Sikorsky Aircraft and has performed work on the S-64, ABC, Rotor Systems Research Aircraft (RSRA), VH-3D, UH-60 Black Hawk and variants, CH-53E Super Stallion, VH-60, RAH-66, S-92, CSAR-X, and the CH-53K(HLR) programs. He has extensive knowledge of weapon's integration and foreign-weapon threat characteristics and has been involved in numerous ballistic subsystem, component, and armor-testing programs and NBC live chemical-agent material-coupon degradation testing efforts. For twelve years, Mr. Burblis assumed lead responsibility for all Boeing/Sikorsky NBC and Ballistic vulnerability-reduction activities on the RAH-66 Comanche Program. He may be reached at 203/386-6092.

# Large Aircraft Survivability Initiative (LASI)

■ by William H. Walters, Jr.

The worldwide proliferation of Man-Portable Air Defense Systems (MANPADS) and the availability of these weapons to terrorists and terrorist organizations has made the protection of large, slow-moving civilian and military aircraft a major concern to both civilian and military decision makers. Figure 1 shows the burning wing of a DHL aircraft after being attacked and hit by a MANPADS in Iraq. The Large Aircraft Survivability Initiative (LASI) is an Air Force initiative begun in early 2003 that encourages partnering between government and industry to address and assess proposed solutions to this threat. Currently, there are over 60 agencies and companies participating in LASI.


Figure 1. MANPADS damage sustained by Airbus A300, 22 November 2003

The second annual LASI conference was held 18–20 April 2006 at Eglin Air Force Base, FL. In addition to six presentation sessions, this year's conference featured an Aircraft Survivability Short Course led by CDR Mark A. Couch (PhD) and a tour of Eglin's Guided Weapon Evaluation Facility (GWEF). GWEF personnel demonstrated how infrared (IR) models of large aircraft are used in both susceptibility reduction and vulnerability assessment studies. High-fidelity, large aircraft Spectral and In-band Radiometric Imaging of Targets and Scenes (SPIRITS) models are converted to Composite Hardbody and Missile Plume (CHAMP) models and subsequently to Real-Time (RTC) CHAMP models, which are used in Hardware-in-the-Loop (HITL) simulations in conjunction with various IR threats to determine hit-point statistical distributions and to evaluate countermeasure (CM) technology effectiveness. Figure 2 is an example of the high-fidelity IR characterizations produced by the GWEF.

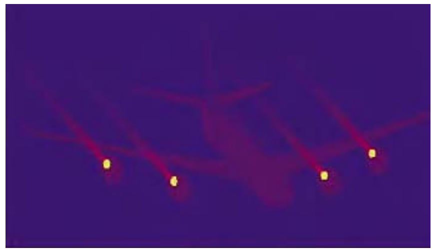


Figure 2. High-fidelity signature characterization of large aircraft

The primary goal of LASI is to make large commercial, commercial derivative, and military aircraft more survivable. LASI provides a forum at which individuals from both government and industry who have a common interest in large aircraft survivability can engage in technical interchange and collaborate in a concerted effort toward furthering that goal. LASI objectives include the following:

- bringing together the full capabilities of the Federal government and industry with the common purpose of improving large aircraft survivability,
- investigating and validating the viability of non-mainstream survivability enhancement alternatives, and
- assessing by demonstration and analysis the survivability of large aircraft.

This year's conference was divided into six sessions:

- Organizational Initiatives
- Threat Coordination
- Damage Modeling and Mitigation
- Aircraft Vulnerability (Engines and Airframes)
- Susceptibility Reduction
- Hazard Protection

Session 1 featured a recap of the previous year's LASI activities, followed by a discussion of Department of Homeland Security (DHS), Joint Aircraft Survivability Program Office (JASPO), and National Aeronautics and Space Administration (NASA) organizational initiatives. Two intelligence/threat briefings were presented during Session 2. Session 3 provided detailed information about ongoing efforts relating to


Civil Reserve Air Fleet Aircraft

Damage Modeling and Mitigation—primarily Modeling & Simulation (M&S) activities. The primary focus of Session 4 was Aircraft Vulnerability; in particular, the vulnerability of control surfaces and engines to MANPADS effects. Session 5 provided information on susceptibility reduction, including both on-board and off-board solutions, and a discussion of Electromagnetic Compatibility and Electromagnetic Interference (EMC/EMI) in large aircraft. Session 6 focused on large aircraft fire protection. Briefings included Fire Prevention and Mitigation, Large Aircraft Wing Fire/Ram Assessment, and Transport Specific Aspects of Survivability.

C-5 Galaxy sits on the flightline

Ongoing collaborations within the LASI community include 747 SPIRITS Model Development, 747 Hit-Point Analyses, 737 SPIRITS Model Development, Radio Frequency (RF) Weapons Threat Characterization and Luggage Evaluation Analysis, Ground-Based Infrared Countermeasures (IRCM) Feasibility Study, Large Engine Vulnerability to MANPADS, Control Surface Vulnerability to MANPADS, MANPADS *vs.* Airliner Wing M&S, and Large Aircraft Fire Protection.

Persons interested in attending future LASI conferences or being included on the distribution list to receive LASI correspondence may contact Mr. Walters at william.walters@eglin.af.mil or Mr. Tony Muccio at anthony.muccio@eglin.af.mil.

Next year's LASI conference is scheduled for 17–20 April 2007. ■

## About the Author

Mr. William H. (Bill) Walters, Jr., is currently a Program Manager in the 780th Test Squadron's Live Fire Office at Eglin AFB, FL. Mr. Walters may be reached at 850/882-4135 or via e-mail at william.walters@eglin.af.mil.

KC-10 in flight

# Designing for Survivability

■ by Dr. Robert E. Ball and Dale B. Atkinson

In this F-14 MANPADS test, conducted under the Joint Live Fire program, the objective was to determine the vulnerability of the F-14 to the threat. The aircraft was placed on a platform and was not operating. First-order effects of the threat were determined, as was the method of firing the threat at a stationary target.

Military aircraft have always had to contend with an enemy who is trying to shoot them down. However, today civilian aircraft also operate in a man-made hostile environment, because of the increased activities of terrorists. As a consequence, survivability for both military and civilian aircraft has become an issue of paramount importance to many governments, commercial airlines, and aircraft companies.

## What is survivability?

Aircraft survivability has been defined as "the capability of an aircraft to avoid or withstand a hostile environment." That environment can be natural, as in the case of severe air turbulence, lightning, midair collisions, and crashes; or man-made, comprising elements such as enemy air defenses or terrorist weapons. When the environment is man-made, the field is referred to as the combat survivability discipline.

To some, survivability in the man-made hostile environment is achieved by flying high, or fast, or at a long range, out of the reach of the enemy's weapons. To others, it is achieved by stealth, and many believe that survivability and electronic warfare (EW) are synonymous. Still others believe a survivable aircraft is one that can take a hit and continue to fly.

These opinions are too exclusive. In the systems engineering approach, survivability is achieved by designing, equipping, and operating an aircraft so that it can avoid the hostile environment, if possible, or withstand the environment, if necessary. In the vernacular of the combat survivability discipline, avoiding the hostile environment is referred to as reducing the susceptibility of the aircraft—the probability that it will be hit by one or more damage mechanisms, such as the blast and fragments from a warhead detonation.

Susceptibility reduction for civil aircraft includes searching baggage and passengers for weapons as they board a flight, policing the area around an airport to prevent a terrorist from taking a shot at a departing or approaching aircraft, developing flight paths that minimize the exposure time to a threat weapon, and using onboard infrared countermeasure equipment to defeat IR surface-to-air missiles such as a manportable air defense system (MANPADS).

Designing an aircraft to withstand a hostile environment is referred to as reducing its vulnerability—the probability it will be killed when hit by damage mechanisms. Examples of vulnerability reduction for civil aircraft include the use of hardened luggage containers that can withstand an internal detonation, the physical separation of redundant hydraulic power systems so that a single hit or detonation will not cause the loss of all hydraulic power, the use of on-board inert gas generators (OBIGGs) to prevent fires and explosions inside fuel tanks, and nacelles that can contain the debris from a damaged engine. Note that the last three features also reduce the probability of a mishap due to a bird strike or fuel tank spark, and consequently also increase the safety of the aircraft.

## Survivability features on U.S. military aircraft

Combat survivability began its evolution as a formal design discipline for military aircraft about 30 years ago, mainly as a result of the loss of approximately 5,000 U.S. military aircraft to enemy fire during the 1962-1973 war in Vietnam. Today, the U.S. DOD develops and procures survivable aircraft.

For example, because approximately 2,500 helicopters were downed in the Vietnam conflict, both the AH-64A Apache and UH-60A Black Hawk were designed to take a single hit by an armor-piercing incendiary round anywhere on the helicopter and continue to fly safely for 30 minutes. This design

requirement paid off when approximately three dozen of the U.S. Army's 101st Airborne Division Apaches on a mission against the Republican Guard near Karbala early in Desert Storm II were heavily damaged by small arms fire. Only one of the Apaches was killed in the battle, a testament to the low vulnerability of the design.

In the A-10 Thunderbolt II, vulnerability was a major consideration during design because of its close-air support mission.

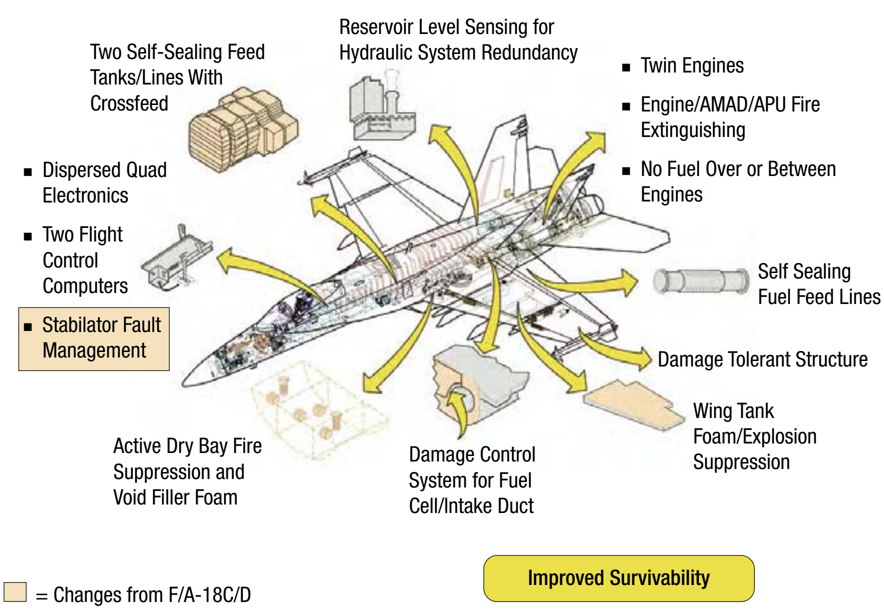
Stealth and electronic countermeasures are important contributors to the survivability of the F-117 Nighthawk, B-2 Spirit, and F/A-22 Raptor, and survivability was one of the four design pillars of the Joint Strike Fighter program. The F/A-18A Hornet was the first Navy aircraft with significant consideration of survivability. The latest version, the F/A-18E/F Super Hornet, has been designed to reduce its radar signatures and is equipped with state-of-the-art defensive electronic countermeasures. Moreover, several vulnerability reduction features have also been added to the already rugged design of this C/D variant.

The V-22 Osprey had significant survivability requirements during design. According to Mike Mikel, the former V-22 survivability IPT leader, the Osprey was designed to a rigorous set of 'Not to Exceed' requirements for a wide range of threats, from small arms to antiaircraft artillery. The design philosophy was to provide state-of-the-art survivability to the most cost-effective levels commensurate with mission effectiveness.

### Survivability and system safety

The system safety discipline attempts to minimize those conditions known as hazards that can lead to a mishap resulting in material damage and personal death or injury in environments that are not made hostile by man. The hazards considered by the system safety discipline can be due to internal system failures or features or to outside influences, such as environmental factors or operator errors. Thus, together, the system safety and survivability disciplines attempt to maintain safe operation and maximize survival of an aircraft and its occupants in all environments, in both peacetime and wartime. An example of the cooperation between the disciplines is the introduction of fuel system fire/explosion protection technology developed for military aircraft into civilian airliners following the loss of TWA 800.

**F/A-18E/F Vulnerability Reduction Through Design**




## MANPADS countermeasure programs

In the late 1990s, the Air Force began a program known as the Large Aircraft Infrared Countermeasures program, or LAIRCM, to reduce the susceptibility of large, slow-flying tanker and transport aircraft such as the C-17 and C-130 to modern shoulder-launched infrared MANPADS (manportable air defense systems) missiles. In 2001, Northrop Grumman's Electronic Systems won the contract to develop and produce the LAIRCM system. It is a laser-based variation of the company's lamp-based directional IR countermeasures system.

The Science and Technology Div. of the Dept. of Homeland Security established the Counter-MANPADS Office to help determine the viability, economic costs, and effectiveness of adapting existing technology from military to commercial aviation use. In early October 2003, a call for proposals was issued to address the IR MANPADS threat.

On January 6, 2004, three contractor teams, BAE Systems, Northrop Grumman, and United Airlines, were awarded Phase I six-month contracts to provide a detailed design and an analysis of the economic, manufacturing, and maintenance issues and solutions needed to support a system that will be effective in the commercial aviation environment.

In August of that year, BAE Systems and Northrop Grumman were selected to proceed to Phase II, which will include the development, test, and evaluation of prototype systems using existing military or commercial technology. Phase II will last approximately 18 months, and

### SURVIAC

Is the DoD center of technical and analytic excellence for nonnuclear survivability and vulnerability data, information, methodologies, models, and analyses relating to US and foreign aeronautical and surface systems is the Survivability/Vulnerability Information Analysis Center (http://iac.dtic.mil/surviac/). SURVIAC collects and maintains combat damage data from most major conflicts, including the Southeast Asia conflict and Desert Storm I. Models developed by the JASPO Survivability Assessment Subgroup are maintained and disseminated by SURVIAC. A Model Guide that describes each of the survivability and lethality models is available from the SURVIAC Central Office.

will be followed by a recommendation to the administration and Congress for the most viable solution to defend against shoulder-fired missiles.

On March 30, 2004, bipartisan legislation to provide additional interim protections for commercial aircraft from shoulder-fired missiles was introduced in the House of Representatives (H.R. 4056). The Commercial Aviation MANPADS Defense Act of 2004, or CAMDA, includes both long-and short-term solutions, as well as domestic and international efforts.

The act is intended to make it clear that while the Dept. of Homeland Security (DHS) is conducting R&D of missile defense equipment for commercial aircraft, interim solutions to the threat posed by MANPADS should be taken. Major provisions include:

- Encouraging the president to pursue international diplomatic and cooperative efforts, including multilateral and bilateral treaties, to limit the availability, transfer, and proliferation of MANPADS and to seek the destruction of excess, obsolete, and illicit systems.
- Requiring the FAA to, when appropriate, expedite airworthiness certification of missile defense systems for commercial aircraft and avoid duplicating the efforts taken by DHS during the missile defense system R&D program.
- Encouraging the president to continue programs to reduce the number of MANPADS worldwide.
- Requiring DHS to report to the Congress, within one year, on the vulnerability assessment reports they are conducting at U.S. airports and any ground-based defense policies or procedures recommended through that process.

A new version of the bill (HR 2905) was introduced in July of this year and referred to the House aviation subcommittee.

## Survivability infrastructure and resources

DOD acquisition policy requires a thorough and systematic survivability program to ensure that it is adequately considered throughout the aircraft design process. This is accomplished in different ways by each of the three departments within DOD.

The principal agencies responsible for Army aviation survivability include the Army Research Laboratory's Survivability and Lethality Analysis Directorate and the Joint Project Office for Aircraft Survivability Equipment and Advanced Threat Infrared Countermeasures/Common Missile Warning System. The Naval Air System Command's Survivability & Threat Lethality Division is the lead agency for the survivability of Navy and Marine aircraft. A major survivability agency within the Air Force is Aerospace Survivability and Safety Flight.

The primary DOD joint service office responsible for aircraft survivability is the Joint Aircraft Survivability Program Office (JASPO), chartered by the Joint Aeronautical Commanders Group. It was formed in January 2003 by combining the Joint Technical Coordinating Group on Aircraft Survivability with several related activities to increase overall effectiveness.

The combined group has a long and dedicated history of developing survivability technology and getting it applied to aircraft through the Vulnerability Reduction and Susceptibility Reduction Subgroups. An example of the technology promoted by the Vulnerability Reduction Subgroup is the OBIGGs. This subgroup played a major role in the development of OBIGGs a number of years ago. Since that time OBIGGs has gone on the C-17, F/A-22, V-22, F-35, AH-64, AH-1Z, UH-1Y, MH-60K, and recently the MH- 47E. The subgroup has recently moved into new fire and explosion technology areas with the potential for large payoffs. Its current passive fire protection work is an example. The enhanced powder panels for fire protection in dry bays and ionomer self-sealing technologies have shown promise and are lightweight enough for unmanned air vehicles.

The Susceptibility Reduction Subgroup continues to develop leading-edge aircraft countermeasures technology, and its products have consistently been applied to new EW systems as they are developed. Aerogel is an example of a promising new technology that was promoted by this subgroup as a retrofitable material for thermal and IR emission suppression in and around aircraft engines. Although many application problems had to be worked out, the material was successfully applied in specific locations to shield aircraft

NAVAIR China Lake's Survivability Division conducted a vulnerability test of a C-130 aircraft by firing a live Stinger missile at it.

hot spots, greatly reducing the IR signature. This technology demonstrated tremendous potential to reduce the susceptibility of current U.S. aircraft to IR-seeking missiles—the Kiowa program manager selected it for a Kiowa upgrade program, and the Apache program is now doing the same.

The tools, models, and simulations needed to design, analyze, test, and evaluate the survivability of U.S. systems are developed and organized within the Survivability Assessment Subgroup. One of their focus areas is survivability model and simulation (M&S) credibility.

The JASPO established the Joint Accreditation Support Activity (JASA) several years ago to assess, improve, and document the credibility of approved survivability models that are provided through the DOD Survivability/Vulnerability Information Analysis Center (SURVIAC). JASA developed a cost-effective verification, validation, and accreditation (VV&A) process that allows programs to tailor their VV&A programs to fit their needs and thus reduce costs. JASA supports acquisition programs and other activities with M&S accreditation support services.

The Joint Combat Assessment Team (JCAT) within the JASPO focuses on collecting combat damage and loss data and showing warfighters what happens when tactics and countermeasures are not fully successful and their aircraft takes a hit. The JCAT is the JASPO's tie to the warfighter. Its primary mission is to deploy combat data collection teams to conduct inspections and forensic analysis of combat-damaged aircraft and incident sites and to interview aircrew, intelligence, weapons and tactics, and logistics personnel.

Survivability is a critical system characteristic that has evolved into a distinct and important design discipline. Viable, cost-effective technologies for reducing the susceptibility and vulnerability of our air systems exist today and are continuing to emerge. ■

*This article first appeared in the November issue of Aerospace America, 2005, pp 32-36, and is reprinted with permission from the American Institute of Aeronautics and Astronautics.*

## About the Author

Dr. Robert E. Ball is a Distinguished Professor Emeritus of the Department of Aeronautics and Astronautics, Naval Postgraduate School (NPS), Monterey, CA. He taught the aircraft combat survivability course at NPS from its inception in 1977 to his retirement in 2000, as well as numerous survivability short courses for both industry and government. He is the author of the First and Second editions of the textbook "The Fundamentals of Aircraft Combat Survivability Analysis and Design," published by the AIAA. He is currently working on a survivability self-study computer program based upon his textbook. He may be reached at reball@redshift.com.

Mr. Dale Atkinson is a consultant on the aircraft combat survivability area. He retired from the Office of Secretary of Defense in 1992 after 34 years of government service and remains active in the survivability community. Mr. Atkinson played a major role in establishing survivability as a design discipline and was a charter member of the tri-service JTCG/AS which is now the JASPO. He was also one of the founders of DoD sponsored SURVIAC. He may be reached at jasnewsletter@jcs.mil.

# Lessons Learned from Live Fire Testing for Improved Survivability

■ by James F. O'Bryon

A project to compile lessons learned from the Live Fire Test and Evaluation (LFT&E) Program has recently been completed. The Director, Operational Test and Evaluation (DOT&E), sponsored this comprehensive compilation of nearly 800 pages. I was contacted by the Office of the Director, Office of the Secretary of Defense (OSD), shortly after my retirement from OSD and asked if I would compile such a collection. I agreed, and the effort has been quite a journey, requiring me to speak with and visit many professionals who have been involved with these efforts over the past two decades.

Recognizing the importance of capturing the various insights gained from the wide variety of both Joint Live Fire Testing and statutory Live Fire Testing (LFT), this compilation should serve as a ready reference of the range of wisdom on survivability and lethality gained from LFT&E since its inception in 1986.

The publication consists of six chapters:

1. Introduction
2. Lessons Learned from Tracked and Wheeled Vehicles
3. Lessons Learned from Ships and Submarines
4. Lessons Learned from Fixed and Rotary Wing Aircraft
5. Lessons Learned from Weapons Lethality
6. Conclusions, Summary, and Bibliography

The Introduction describes the intended use of the compilation, presents an executive summary, and gives a brief history of LFT. While chapters two through six deal with specific lessons learned on roughly 100 specific platforms and weapon systems, the book also looks across weapons systems in an attempt to draw some "LFT&E Best Practices" that could apply across multiple systems. These are included in Section 1.7, providing over 100 general lessons that may apply to a broad variety of LFT&E activities.

In the early stages of assembling the myriad of lessons learned, I quickly discovered that it would be very helpful to try to "bin" the lessons learned into categories that would help a user wade through them and make better use of them. As a result, the book places lessons learned into seven categories, as follows:

**Design Insights/Shortcomings/Changes**—These lessons learned include discoveries in the physical design of a system that were either found to be deficient or identified as a particularly noteworthy design feature. Other insights that had a significant impact on the overall design of the system also fall into this category.

F-15E Strike Eagle

**Safety and User Casualties**—The legislation governing LFT&E calls out for reducing personnel casualties as its prime focus. Hence, including this category of lessons learned was felt to be important. It addresses both sources of injury and methods to minimize combat injury.

**Tactics, Training, and Doctrine**—Lessons learned in this category involve insights gained from LFT&E that had a positive influence on the way the system is deployed and how training is performed or involve other issues that impacted non-materiel improvements.

**Battle Damage Assessment and Repair (BDAR)**—This category addresses lessons learned from efforts to repair damage inflicted from LFT&E and Joint Live Fire (JLF) tests. They include discussions regarding unexpected damage, repair methods, new materials, and related repair approaches.

**Modeling and Simulation**—This category addresses simulations that were used in design, development, test, and evaluation of the system. These lessons learned include discussions of areas in which pre-test predictions were compared with test outcomes and what particular strengths and weaknesses were identified in those models.

**Test Planning, Design, Instrumentation, and Resources**—In this category, lessons involving LFT&E test planning, assuring adequate funding and test hardware, general test management, and related topics are addressed.

**Other Related Insights/Comments**—Because some lessons learned don't fit conveniently into one or more of the aforementioned categories, this category is reserved for other lessons learned or comments that were deemed important.

Throughout the book, each category has its own distinct color header to assist readers in tracking a particular category from system to system.

While the book contains lessons learned for approximately 100 systems, including air, land, and sea, of particular interest to readers of Aircraft Survivability would obviously be the lessons learned on aircraft, both fixed wing and rotary wing. These are presented in Chapter 4.

### Fixed-Wing Aircraft

- A-10 Thunderbolt II
- Airborne Laser (ABL)
- AC-130U Gunship
- AV-8B Harrier
- B-1B Conventional Mission Upgrade Program (CMUP)
- B-2 Spirit
- C-5 Avionics Modernization Program (AMP) and Reliability Enhancement and Re-Engineering Program (RERP)
- C-17A Globemaster III Airlift Aircraft
- C-130 Avionics Modernization Program (AMP)
- C-130J Airlift Aircraft
- KC-130J Airlift Aircraft
- F-14 Tomcat
- F-15 Eagle
- F-16 Fighting Falcon
- F/A-18 A/B/C/D Hornet
- F-A-18 E/F Super Hornet
- F/A-22 Raptor Advanced Tactical Fighter (ATF)
- F-35 Lightning Joint Strike Fighter (JSF)

### Rotary-Wing Aircraft

- AH-1S Huey Cobra Helicopter
- AH-64D Longbow Apache Helicopter
- CH-47 F Chinook Improved Cargo Helicopter (ICH)
- CH-60S Fleet Support Helicopter
- H-1 Helicopter Upgrades (USMC)
- MH-47 Chinook SOA and MH-60K SOA
- MH-60R Black Hawk Helicopter
- MH-60S Fleet Combat Support Helicopter
- OH-58D Kiowa Warrior Helicopter
- RAH-66 Comanche Helicopter
- SH-60B and HH-60H Helicopter
- UH-60A/M Black Hawk Helicopter
- V-22 Osprey Tilt-Rotor

The lessons learned for these 31 aircraft—18 fixed wing and 13 rotary wing—vary widely in number and detail. Some aircraft, however, such as the ABL and the KC130J, have few, if any, lessons learned included in the compilation. This is because they are either still under test, test results are not yet released, or their lessons learned are classified; hence, the information is not included in this compilation. Conversely, other aircraft have extensive descriptions of lessons learned presented because of their maturity and extensive testing and reporting.

Each system also includes an extensive bibliography, including technical references, Congressional references, and references to LFT&E and JLF in the open literature. Over 1,000 references are included to assist in tracking other lessons learned and to provide background information regarding these tests.

While the lessons learned compilation is unclassified, it does not have unlimited distribution. The Office of the Deputy Director, OT&E/LFT&E, or the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) controls its distribution.

The compilation has been published in two formats: a hard-bound book and a CD ROM. The CD is searchable by keyword and also includes a number of hyperlinks to other, related information.

For further information on this project, contact the DOT&E, Operational Test and Evaluation, OSD, at 703/614-3991. ■


CD version of publication "Lessons Learned from Live Fire Testing: Insights Into Designing, Testing, and Operating U.S. Air, Land, and Sea Combat Systems for Improved Survivability and Lethality"

## About the Author

Mr. James F. O'Bryon served for over 15 years as the first Director, Live Fire Testing, in the Office of the Director, Operational Test and Evaluation, Office of the Secretary of Defense. He is a graduate of The King's College, George Washington University, and Massachusetts Institute of Technology.

# Calendar of Events

## OCT

**24–27, Williamsburg, VA**
AHS/AAAA Helicopter Military Operations Technology (HELMOT) Specialists' Meeting XII
www.aaaa.org

**25–27, Dearborn, MI**
2006 TACOM APBI
Nery Cruz, 703/247-9464,

**29 Oct–3 Nov, Monterey, CA**
77th Shock and Vibration Symposium
joel.leifer@saviac.org

**30 Oct–1 Nov, Panama City, FL**
44th Annual Targets, UAVs & Range Operations Symposium & Exhibition
Ms. Simone L. Baldwin, 703/247-2596,

**30 Oct–2 Nov, Lake Buena Vista, FL**
Annual ITEA International Symposium
Mr. Charles E. "Pete" Adolph, 505/856-6947,

**30 Oct–3 Nov, Miamisburg, OH**
Aircraft Fire Protection and Mishap Investigation Course 16th Annual International Course
AFP Associates, Inc., 937-434-8030

## NOV

**6–9 Nov, Monterey, CA**
Aircraft Survivability 2006-Exploiting the Synergy Between Civil & Military Aircraft Survivability
jhylan@ndia.org

**14–16 Nov 2006 Monterey, CA**
AIAA Missile Sciences Conference
AIAA, www.aiaa.org

**14–16 Nov, Nellis AFB, NV**
Winter JMUM 2006
Paul Jeng, 937/255-3828 x273,

**27–28 Nov, San Antonio,TX**
Global Border Security Conf and Expo
www.globalbordersecurity.com

## DEC

**5–8 Dec, Atlanta, GA**
Infrared Countermeasures
http://www.emarket.gatech.edu/sensiac/2006_SENSIAC_COURSES.html

Information for inclusion in the Calendar of Events may be sent to:

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